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Sounder Options in the GOES-R Era

5th GOES Users Conference/ 2008 AMS Meeting

New Orleans

presented by

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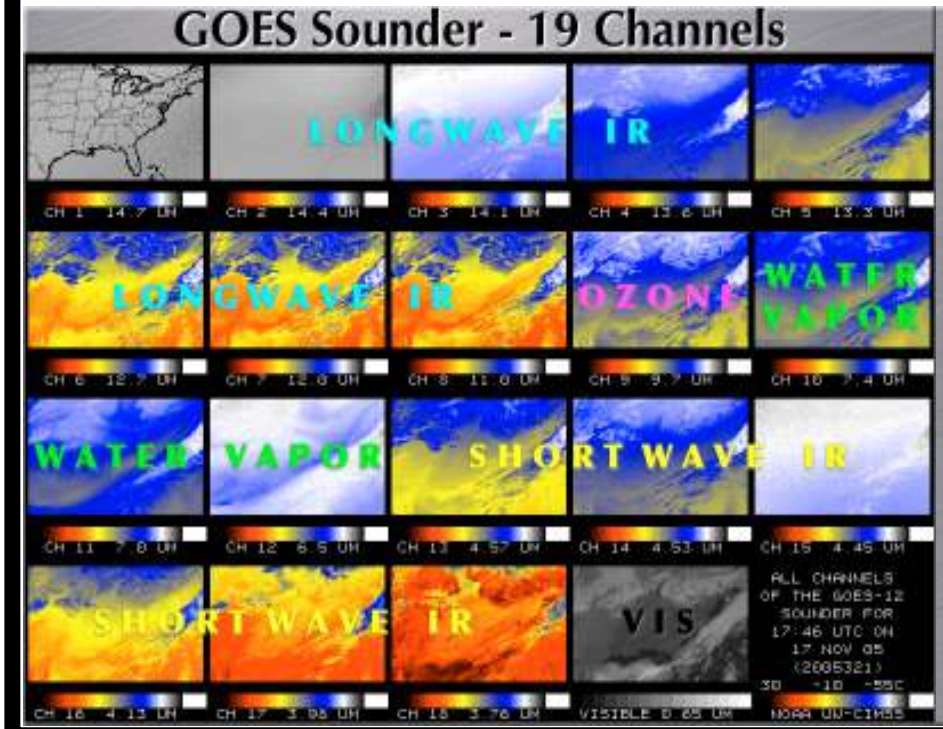
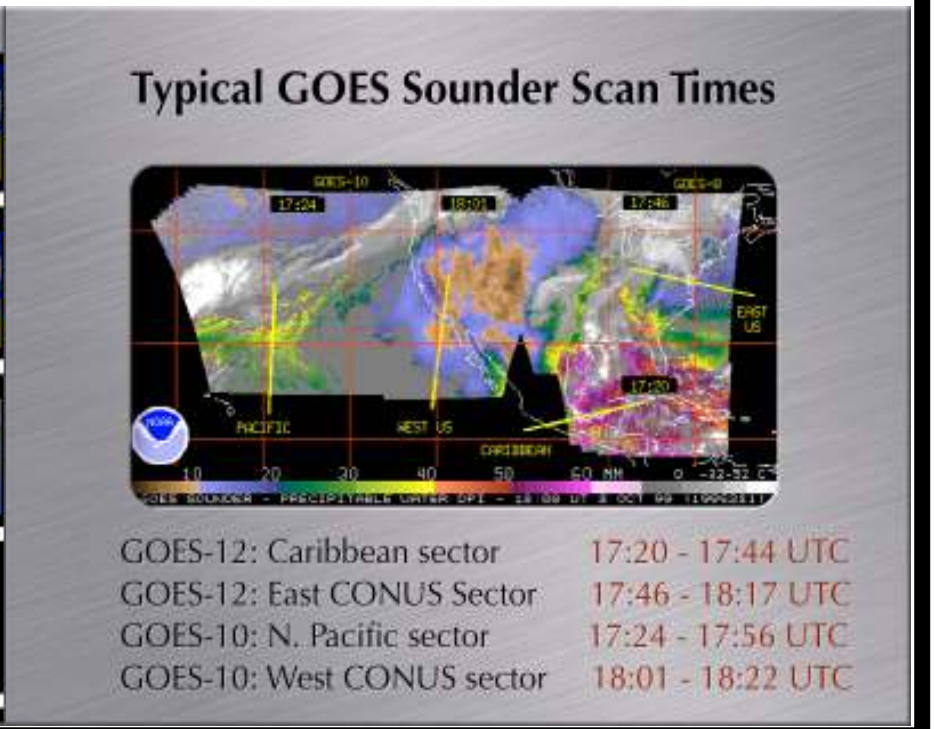
ABSTRACT

- Operational Sounder Products are an essential component of the expected benefits of the GOES-R Program. Despite programmatic decisions which have led to the loss of a dedicated Sounder on the GOES-R Spacecraft, options do exist to provide a significant improvement over current GEO sounding capabilities. We will compare the cost, benefits and risks of these options to show that Advanced Operational Sounding is practical to implement and provides unique capability to improve severe weather, hurricane, aviation weather, NWP and climate change forecasting.

Current GOES Sounder provides useful Operational Products, but with limited coverage.

- 19 channels (18 Infrared; 1 Visible)
- Spatial resolution: ~ 10km
- Hourly scanning over CONUS and adjacent waters
- Products include standard imagery and derived, Level-2 products





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Slide is courtesy of Jun Li,
Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin-Madison

Current GOES Sounder Operational Products

- Clear-Sky Radiances
- Layer & Total Precipitable Water
- Cloud-top Retrievals
- Surface Skin Temperature
- Profiles of Temp and Moisture (40 levels)
  - Point Soundings
- Atmospheric Stability Indices
- Water Vapor Winds

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Advanced Geo Sounding GOALS

Future GOES

Future GOES will address all four key remote sensing areas

* spatial resolution – what picture element size is required to identify feature of interest and to capture its spatial variability;
* spectral coverage and resolution – what part of EM spectrum at each spatial element should be measured, and with what spectral resolution, to analyze an atmospheric or surface parameter;
* temporal resolution – how often does feature of interest need to be observed; and
* radiometric resolution – what signal to noise is required and how accurate does an observation need to be.

Paul Menzel, GOES User Conference, June 2006

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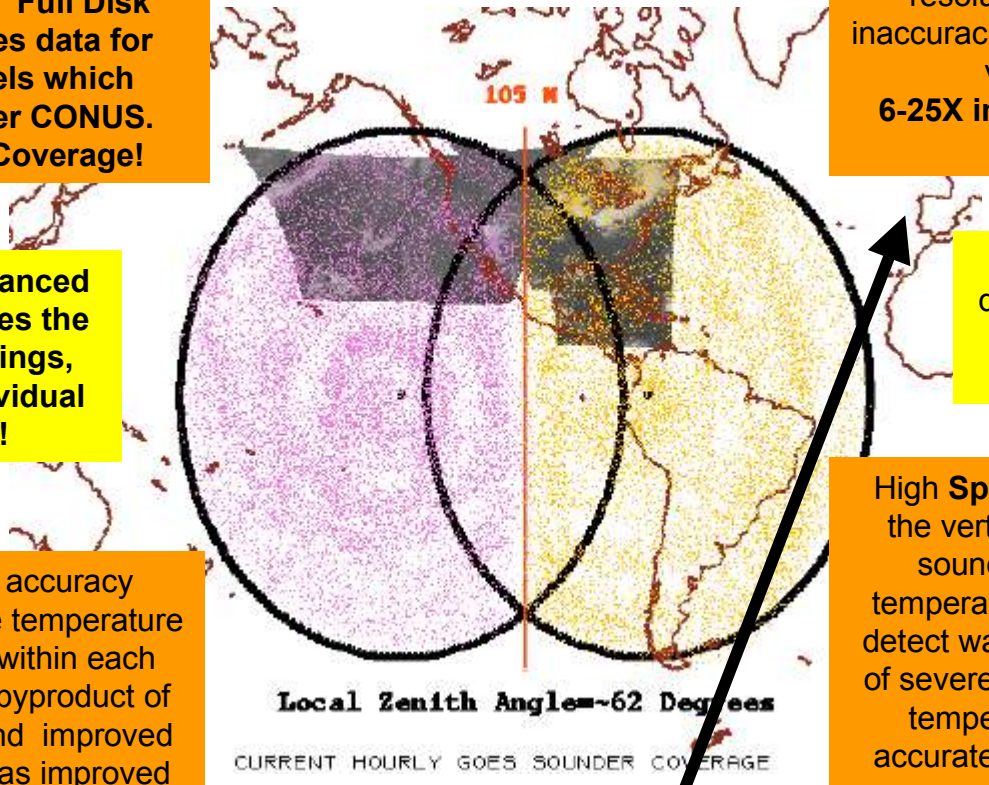
Improved **temporal** and spatial coverage allows the advanced sounder to observe the full disk in the same time or less than the current sounder observes CONUS!
Without timely, fulldisk sounding, hurricanes outside of CONUS cannot even be seen! Full Disk coverage also provides data for global weather models which improve forecasts over CONUS.
10x Improvement in Coverage!

These increase the total NUMBER of Soundings

High **spatial** resolution (2-4km) increases the number of individual soundings and the number of "clear air" soundings. These "clear air" soundings are important weather model inputs and enable more accurate forecasts. High spatial resolution reduces the retrieval inaccuracies due to clouds and surface variations over land.
6-25X improvement in number of soundings

Each feature of the Advanced Sounder either increases the total number of Soundings, the quality of each individual sounding or Both!



The figure compares the difference in coverage for the current Sounder vs the Advanced Sounder

Improved **radiometric** accuracy improves the quality of the temperature and water vapor values within each vertical profile. This is a byproduct of both improved spectral and improved spatial resolution as well as improved detectors.
50-200% improvement.

These increase the QUALITY of each Individual Sounding.

High **Spectral** Resolution increases the vertical resolution of individual soundings of water vapor and temperature. Improves the ability to detect water vapor features indicative of severe weather. Improves surface temperature over land by more accurate characterization of surface temperature.
2-3x Improvement in vertical resolution, 50% improvement in temperature and water vapor accuracy

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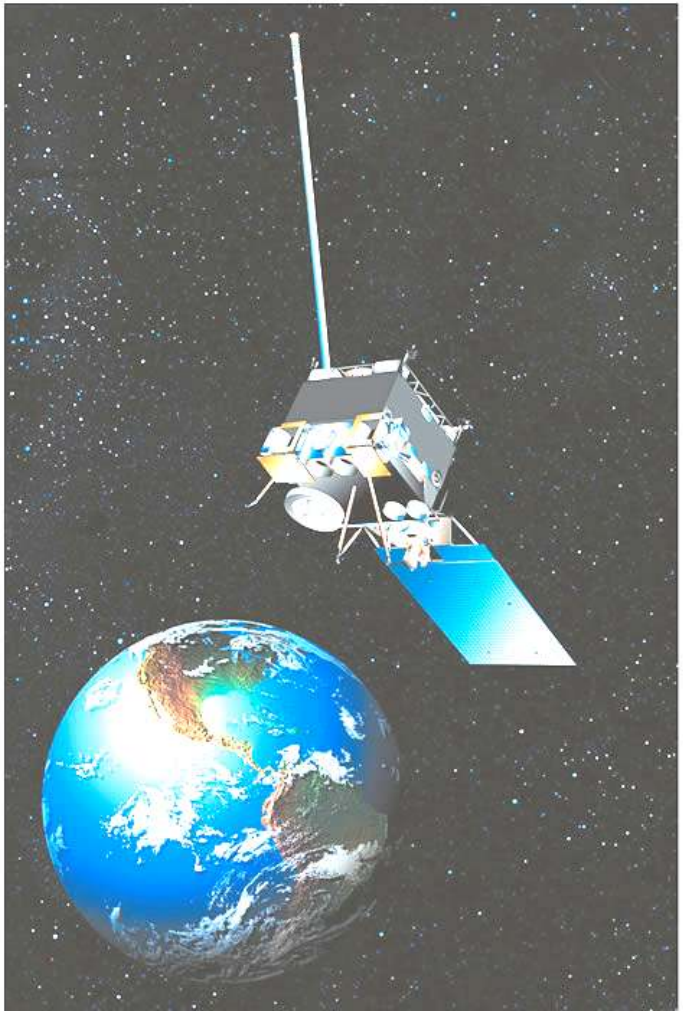
Evolutionary Approach to an Advanced Geo Sounder

- **Need low cost and low risk solution with a robust capability to meet advanced sounder goals.**
- **Leverage NOAA investments**
  - GOES-N class legacy sounder bands and algorithms
  - No/low impact on ground architecture and/or numerical models
  - Leverage HES and ABI developments
- **User needs/desires**
  - No impact to ABI program
  - Increased performance compared to GOES-N
  - Flexible design to significantly improve temporal, spatial and radiometric performance
  - Path to high spectral resolution.



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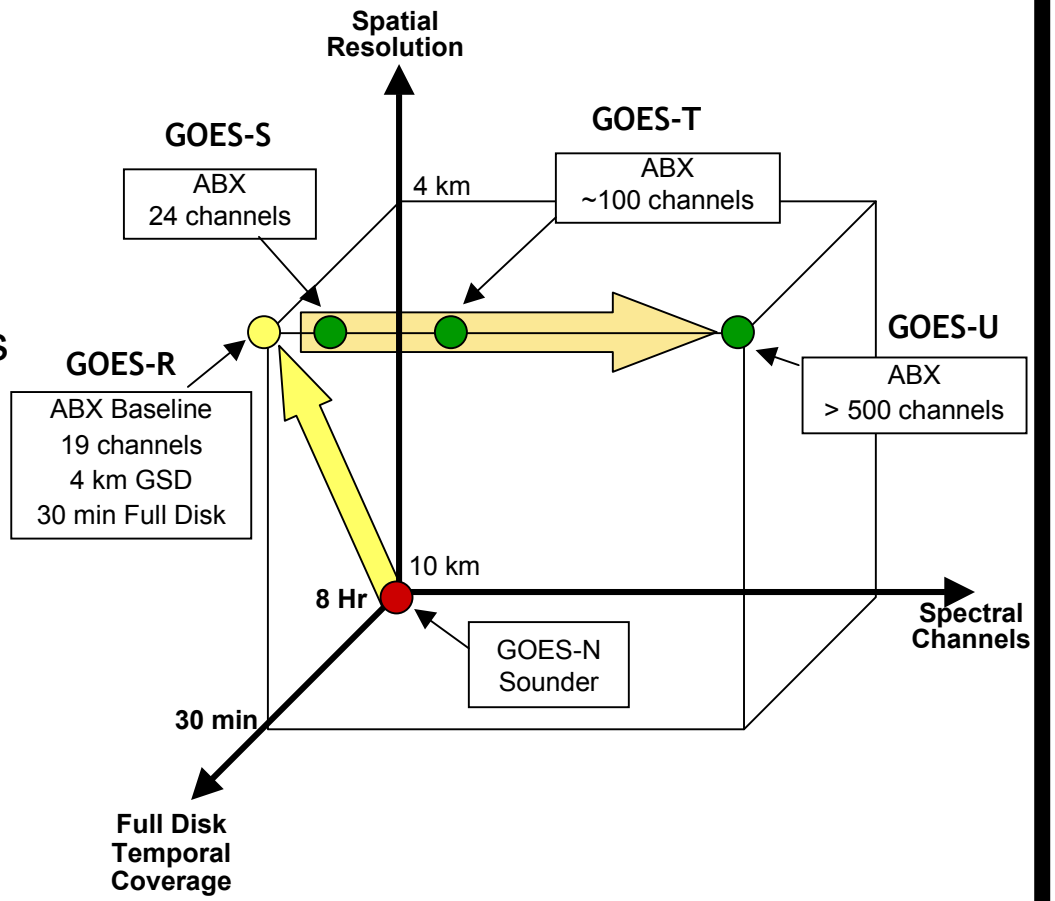
ABX Provides considerable improvement over the GOES-N Class Sounder

- ABX Sounder architecture is a simple derivation of the ABI design (94% reuse)
  - Leverages Government investment in the ABI.
  - Parts, Long-lead items, production, integration and test facilities in place.
- GOES-N Class technologies
  - Low risk filter technology
  - Low risk modifications to the ABI design
  - Separate Imager and Sounder instruments
- GOES-N Class Spectral Coverage
  - 18 IR + 1 VIS channel
  - No change to ground processing algorithms
- Spacecraft Accommodations on the order of ABI
  - ABI footprint is GOES-N class
  - ABI/HES-like volume and power
  - Data rate an order of magnitude lower that ABI and HES
- Improved performance satisfies primary NWS and NWP User needs
  - 20-60 minute Full Disk coverage and 5-15 min CONUS coverage (vs. 8 hour and 1 hour)
  - 4 km spatial performance with potential for 2 km (vs. 10km)
  - Potential to add channels to allow some trace gas monitoring or water vapor micro-channel observation
  - Improved radiometric performance and SNR over current GOES N Sounder. (factor of 2x or more)

Flexible Design for Enhanced Performance

- ABI was designed to add more IR bands within same optical structure
- Incremental improvements without complex system design
  - Increased IR spectral bands
  - Significant Cooler margin to allow for hyperspectral aft-optic assembly
  - some CW capability at (0.5km resolution)
- Low cost/low risk path to near-HES performance (>500 Bands)



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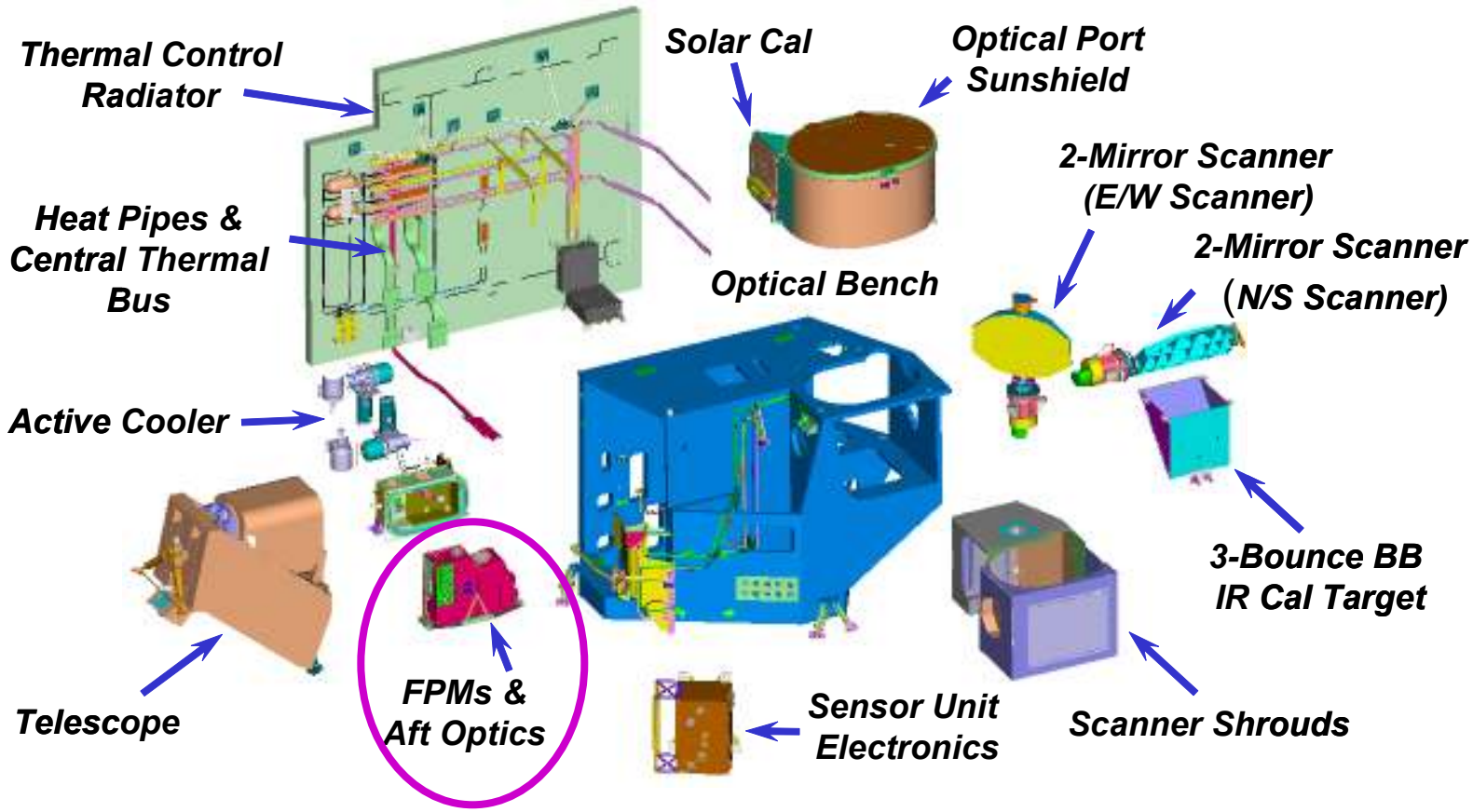
ABI Has all Subsystems to Support Sounding Mission



Modifications limited to FPM and Aft Optics modules

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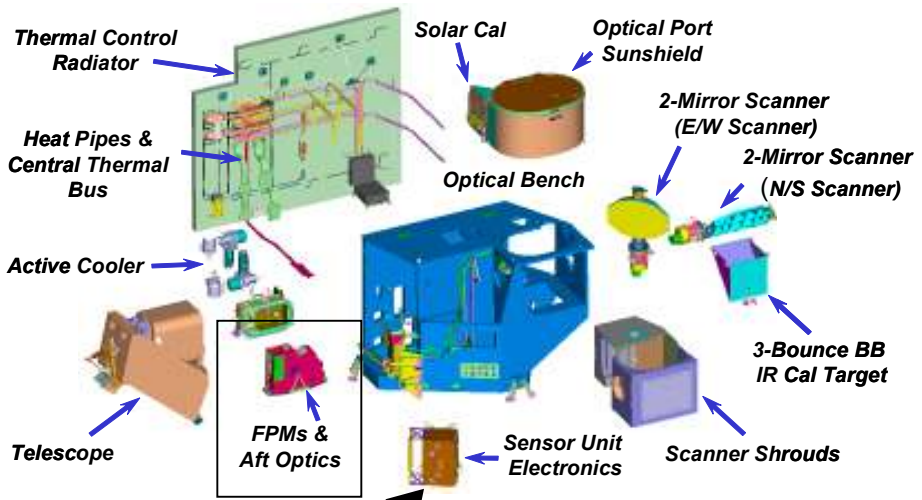
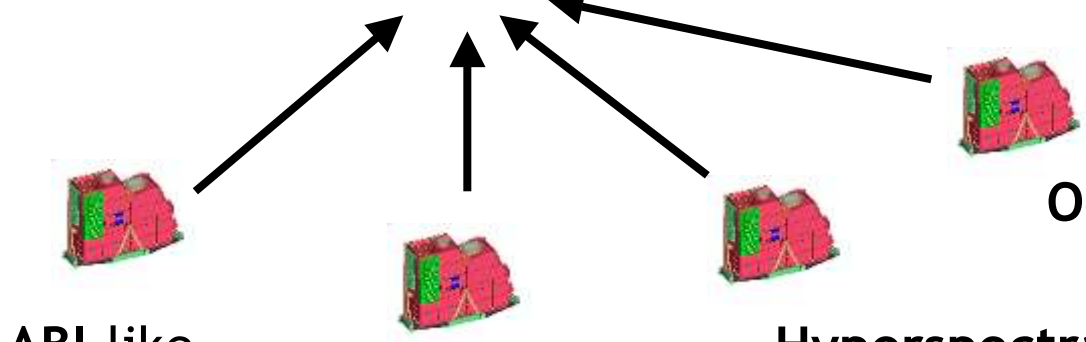
Multiple Aft Optics Assemblies can be developed and integrated as needed



By limiting development to the Aft Optic Module, maximize utility, flexibility reuse is realized at minimal cost and risk.



ABI-like

GOES-N Bands

Hyperspectral

Ocean Color / Custom

Multiple Aft Optics modules can be built, developed simultaneously and integrated as needed.

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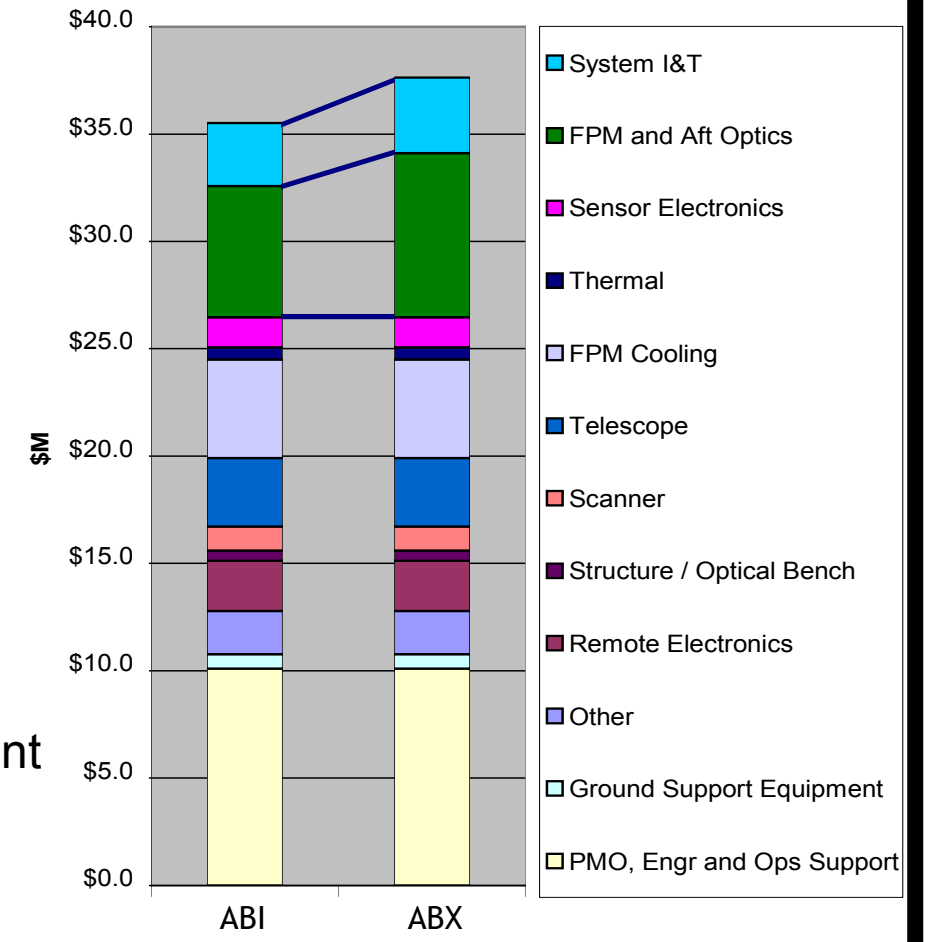
94% ABI Reuse Reduces Cost and Risk

- Common subsystems
  - Eliminates most NRE
  - Streamlines supply chain
  - Streamlines production, test and integration
- Reduced Risk
  - Limited development
  - High TRL
  - Eliminates most unique test and integration processes and equipment
- Highly reliable cost model
  - Most costs already known



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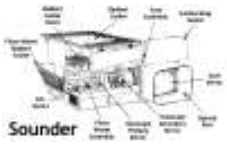
Physical Comparisons

Specification	GOES-N 	HES TS-11	ABI 	ABX 	HES 
Dimensions (m)	X=1.37 Y=0.80 Z=0.75	X=1.50 Y=1.00 Z=1.50	X=1.55 Y=1.12 Z=1.45	X=1.55 Y=1.12 Z=1.45	X=1.68 Y=1.32 Z=1.49
Mass (kg)	152	210	294	~300	308
Power (watts)	149	285	318	~330	502
Avg Data Rate (Mbps)	0.40 No compression	6.6	51.5 Rice compression	<5.0 No Compression	52.1 Rice compression

A Comparison of the ABX against GOES-N, ABI and HES shows spacecraft accommodations required are on the order of ABI

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ABI/GOES Heritage Drives Program Efficiencies

- Sensor cost
  - Directly compatible with ABI test program, test procedures, test equipment, and fixtures
  - Supply chain efficiencies
  - Integration into manufacturing flow
  - Utilize ABI-trained workforce
- Spacecraft integration cost
  - Identical electrical, mechanical and thermal interfaces
  - Identical integration and test plan/procedures
  - Earlier spacecraft T/M/E interface designs
- Total system cost
  - Data assimilation, algorithms, NWP, communications, and archive

ABI-Driven Performance Enhancements/Synergies

- Improved temporal scan rate
  - Full disk: 20 min vs 8 hr
  - CONUS: 5-8 min vs 1 hour
- Improved spatial resolution: 4 km vs 10 km
- Improved radiometric accuracy
- ABI Flexible Scan capability to focus on regional and developing severe weather
- Synergies
  - Cross-calibration for ABI
  - Backup for ABI visual bands
  - Backup imager
- No impact on the ABI program!

Cost Estimates

- Recurring is roughly equivalent to ABI
  - Non-recurring costs for sounding design estimated $20-$30M
- Baseline modifications for soundings
  - Requires beam splitter, filters and IR focal planes
- Further ABX Enhancements
  - Additional beam splitters and focal planes to expand beyond baseline
  - For near-HES performance, additional analysis is required to refine engineering tasks and cost

Backup Slides

Possible Sounder Scenarios in GOES-R Era

- Nothing (Use ABI to produce current Sounder Products)
  - Does Not meet Advanced Sounder Goals
- GOES-N Class Sounder (Reproduce current Sounder capabilities over CONUS)
  - Does Not meet Advanced Sounder Goals
- Advanced Sounder (Unlikely to fly on GOES before T)
  - ABX- GOES-N Bands - Meets 3 of 4 Advanced Sounder Goals
  - ABX- Hyperspectral - Meets Advanced Sounder Goals
- Commercial Sounder
  - ABX-GOES-N Bands - Meets 3 of 4 Advanced Sounder Goals
  - ABX-Hyperspectral - Meets Advanced Sounder Goals
  - GIFTS - Meets some Advanced Sounder Goals

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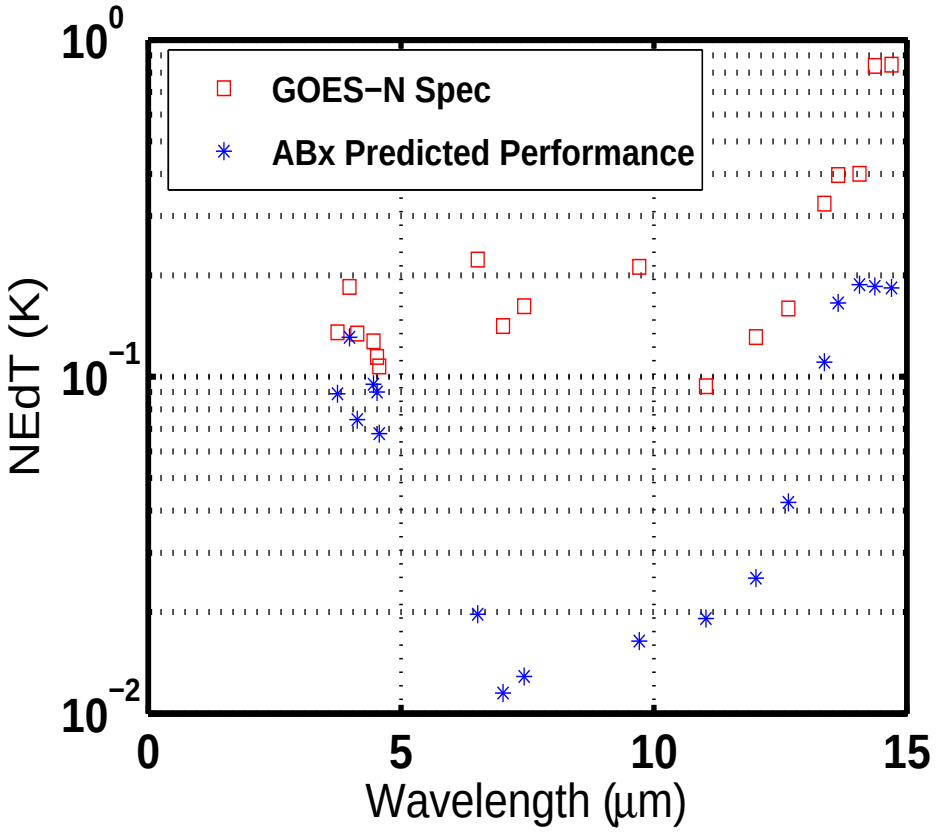
ABX Concept Meets GOES-N Noise Requirements



Use ABI design as-is, except

- Replace spectral filters
- Add a beamsplitter and one IR FPA

4 km IFOV

- Aggregate 2 km samples
- 5 minute full disk coverage

2 km IFOV

- Divide scan rate by 4
- Multiply integration time by 4
- 20 minute full disk coverage

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Predicted NEdNs for 19 Channel ABX Concept

Channel	Wavelength (um)	Wavenumber	NEdT (300 K reference)	NEdN (mW/m^2/sr/cm^-1)	GOES-N Spec (mW/m^2/sr/cm^-1)	SNR
1	0.696	14368				321
2	3.744	2671	0.0905	0.0024	0.0036	
3	3.979	2513	0.1307	0.0058	0.0082	
4	4.132	2420	0.0739	0.0044	0.008	
5	4.454	2245	0.095	0.0097	0.013	
6	4.525	2210	0.0899	0.0102	0.013	
7	4.57	2188	0.0677	0.0082	0.013	
8	6.515	1535	0.0196	0.0132	0.15	
9	7.018	1425	0.0115	0.0097	0.12	
10	7.435	1345	0.0129	0.0127	0.16	
11	9.71	1030	0.0164	0.0255	0.33	
12	11.03	907	0.0192	0.0327	0.16	
13	12.02	832	0.0252	0.0442	0.23	
14	12.66	790	0.0424	0.0744	0.28	
15	13.37	748	0.1104	0.1927	0.57	
16	13.643	733	0.1655	0.2875	0.69	
17	14.065	711	0.1877	0.3229	0.69	
18	14.37	696	0.1854	0.3163	1.43	
19	14.7	680	0.1836	0.3100	1.43	

Wavenumber (cm^{-1})	Wavelength (um)	NEdN (mW/m^2 sr cm^{-1})	NEdT @ 250K (K)
650	15.38	1.265	1.036
670	14.93	0.40	0.31
700	14.29	0.212	0.175
750	13.33	0.176	0.147
800	12.50	0.166	0.146
950	10.53	0.182	0.191
1150	8.70	0.310	0.483
1200	8.33	0.529	0.918

Wavenumber (cm^{-1})	Wavelength (um)	NEdN (mW/m^2 sr cm^{-1})	NEdT @ 250K (K)
1210	8.26	0.096	0.24
1258	7.95	0.053	0.13
1740	5.75	0.083	0.74
1741	5.74	0.022	0.20
2150	4.65	0.028	1.57

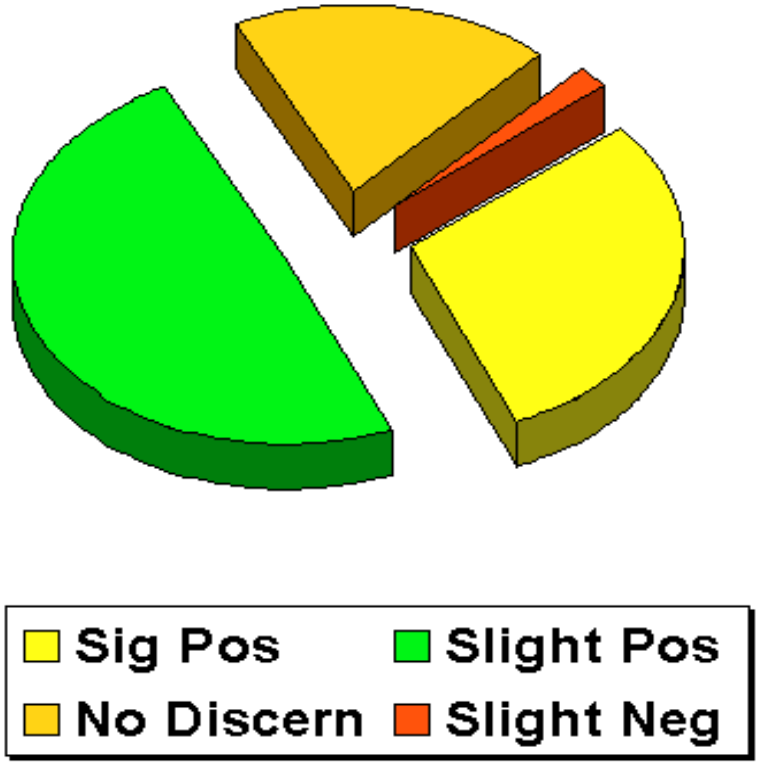
Wavenumber (cm^{-1})	Wavelength (um)	NEdN (mW/m^2 sr cm^{-1})		NEdT @ 250K (K)	
		THRESHOLD	Goal	THRESHOLD	Goal
2150	4.65	0.028	NA	1.57	NA
2250	4.44	0.03	NA	2.57	NA
2251	4.44	0.010	0.003	0.6	0.2
2720	3.68	0.013	0.004	5.03	1.68

Discussion

- In the GOES-R Era we are facing the possibility of reduced GEO sounding capability.
- The Need and benefit of Advanced GEO sounding has been documented by multiple sources and agencies.
  - NOAA CBA for GOES-R Imager and Sounder (2004)
  - Eumetsat Observational Priorities for MTG
  - WMO recommendations for GEOSS
- Advanced Geo Sounding is achievable with minimal risk and cost.

Multi-Band Sounder still has useful utility, but is limited by poor temporal and spatial resolution and coverage

NWS Forecast Office Assessment of GOES Sounder Atmospheric Instability



Summer 99 Forecaster assessment of usefulness of changes in hourly LI, CAPE, & CINH product for predicting location/timing of thunderstorms

Out of 248 valid weather cases:

- Significant Positive Impact (30%)
- Slight Positive Impact (49%)
- No Discernible Impact (19%)
- Slight Negative Impact (2%)
- Significant Negative Impact (0)

Figure from the National Weather Service, Office of Services

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NWS and JCSDA Have Need for non-Hyperspectral Sounder products

- Difficulty ingesting hyperspectral data.
- Difficulty in assimilating data effected by surface emissivity uncertainties and clouds.
- Current sounder has only limited utility over CONUS, no utility over Full Disk and no mesoscale mode.
- NWS has expressed desire for existing GOES-N bands at higher temporal and spatial resolution with full disk and mesoscale coverage capability.
- A capable full disk and mesocale multi-band sounder will build a demand for a hyperspectral sounder in the future.

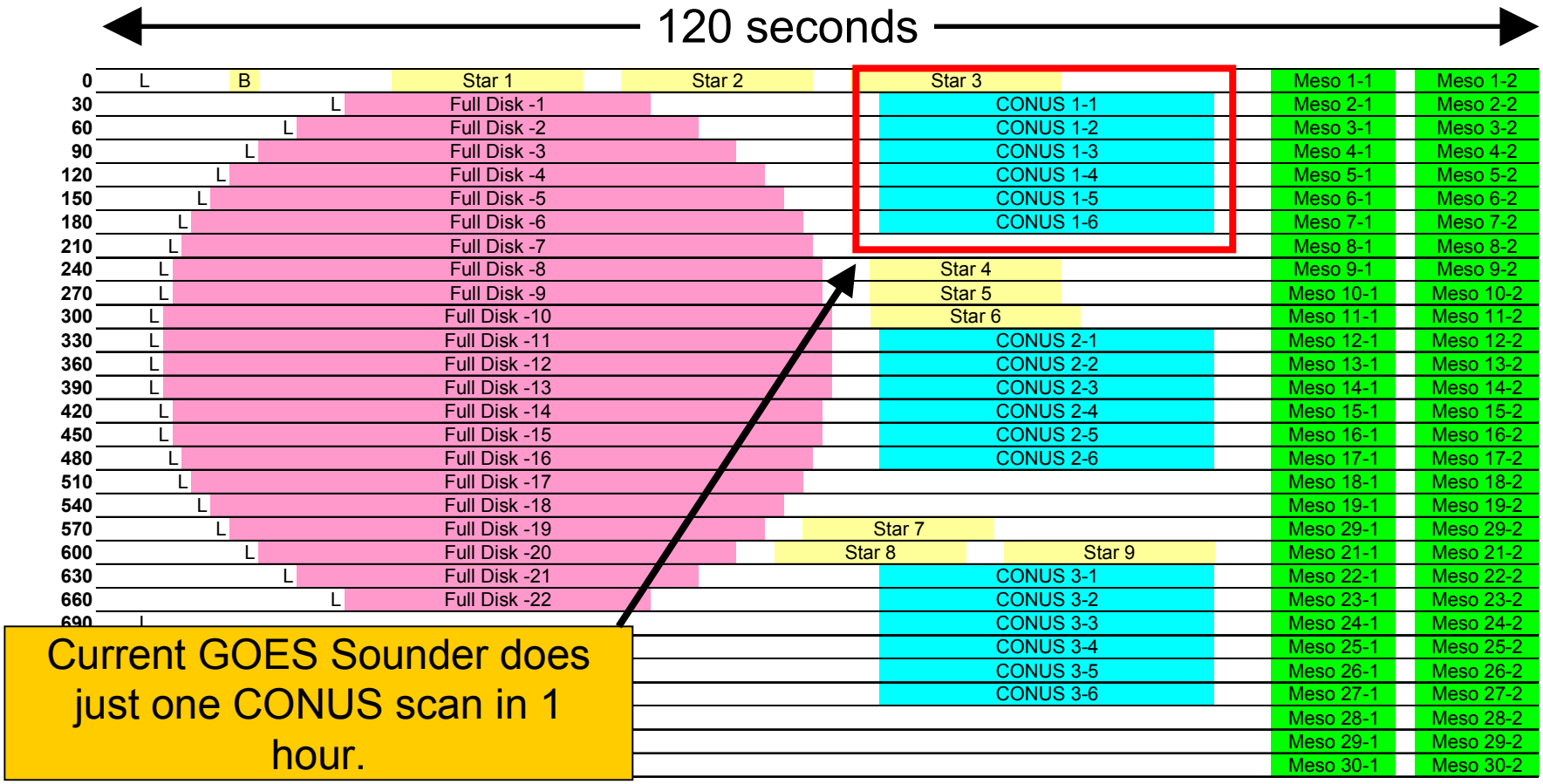
Significantly improved capability over GOES-N Class Sounder

- Improved Temporal (up to 32x)
- Improved Spatial (2-4km continuous vs 10km on 50km centers)
- Improved Coverage (Full Disk, with CONUS and Meso)
- Improved Radiometric (exceeds GOES-N SNR by 50-100%)
- Information content of ABX compared to GOES-N is ~1000x

ABI-Driven Performance Enhancements/Synergies

- Improved temporal scan rate
  - Full disk: 20 min vs 8 hr
  - 1000 km x 1000 km: 5-8 min vs no capability
  - Mesoscale scan: 2-3 min vs no capability
- Improved spatial resolution: 2-4 km vs 10 km
- Improved radiometric accuracy
- ABI Flexible Scan capability to focus on regional and developing severe weather
- Synergies
  - Cross-calibration for ABI
  - Backup for ABI visual bands
  - On Orbit backup for ABI mission
  - Backup imager
- No impact on the ABI program!

ABX Mode 3 Timeline Delivers High Quality Data



In this mode, 2km resolution is assumed producing 1 FD, 3 CONUS, 60 Mesoscale

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